Stanford WOODS INSTITUTE for the ENVIRONMENT

Research Brief

SPRING 2018

Profitable Opportunities for Carbon Removal During Biofuel Production

Background

Removing carbon dioxide (CO_2) from the atmosphere, called CO_2 or carbon removal, has a critical role in fighting climate change, enabling stringent emissions reductions in energy and land systems worldwide. One way to achieve such negative emissions is by harvesting plants, which grow by removing CO_2 from the atmosphere. The plant mass, called biomass, is used to generate energy, and the resulting CO_2 emissions are captured and permanently stored in geologic formations deep underground. Technologies with this capability, known as bioenergy with carbon capture and sequestration (BECCS), feature prominently in scenarios that limit warming to the Paris Agreement goal of well below 2°C above preindustrial levels, as assessed by the Intergovernmental Panel on Climate Change and others.

About the Researchers

This research was led by **Daniel Sanchez**, a postdoctoral research scientist at the Carnegie Institution for Science, in partnership with **Nils Johnson**, International Institute for Applied Systems Analysis; **Sean McCoy**, Lawrence Livermore National Laboratory; **Peter Turner**, Carnegie Institution for Science; and **Katharine Mach**, Stanford University Earth System Science and the Stanford Woods Institute for the Environment.

Although potentially essential to achieving climate goals, most BECCS technologies are technically immature or commercially unavailable. Research and development is necessary to reduce costs, improve performance, and clarify their sustainable scale. Concerns include the viability of large-scale deployments, ranging from

Photo: Archer Daniels Midland

CO_2 from ethanol fermentation has been used for enhanced oil recovery (EOR) and sequestered in deep saline aquifers. The Illinois Industrial CCS project in Decatur, Illinois, captures 1 million metric tons of CO_2 per year from a corn ethanol facility with 300 million gallon capacity, for sequestration in the Mt. Simon Sandstone, a saline aquifer.

land and water requirements, to the feasibility of CO_2 pipeline networks, to the commercialization of advanced bioenergy technologies.

In contrast, examples of carbon removal from biofuels production already exist at scale. Practiced commercially for several decades, fermentation of sugars and starch currently produces over 26 billion gallons of ethanol each year worldwide. Because ethanol production through fermentation produces a high-purity stream of CO_2, capturing the CO_2 and compressing it for injection underground are cheaper than from other sources—and possible with existing technologies.

In this brief, we examine low-cost, commercially ready carbon removal opportunities for existing biorefineries in the United States. Our analysis combines process engineering, spatial optimization, and lifecycle assessment to consider the technical, economic, and institutional feasibility of capturing and storing CO_2 through existing infrastructure, technologies, and policies. The analysis informs decisionmaking that seeks to enhance both near-term and long-term efforts to fight climate change by deploying existing technologies and developing new approaches for carbon removal.

Key Findings

Deployment of carbon removal from biorefineries is cost-effective:

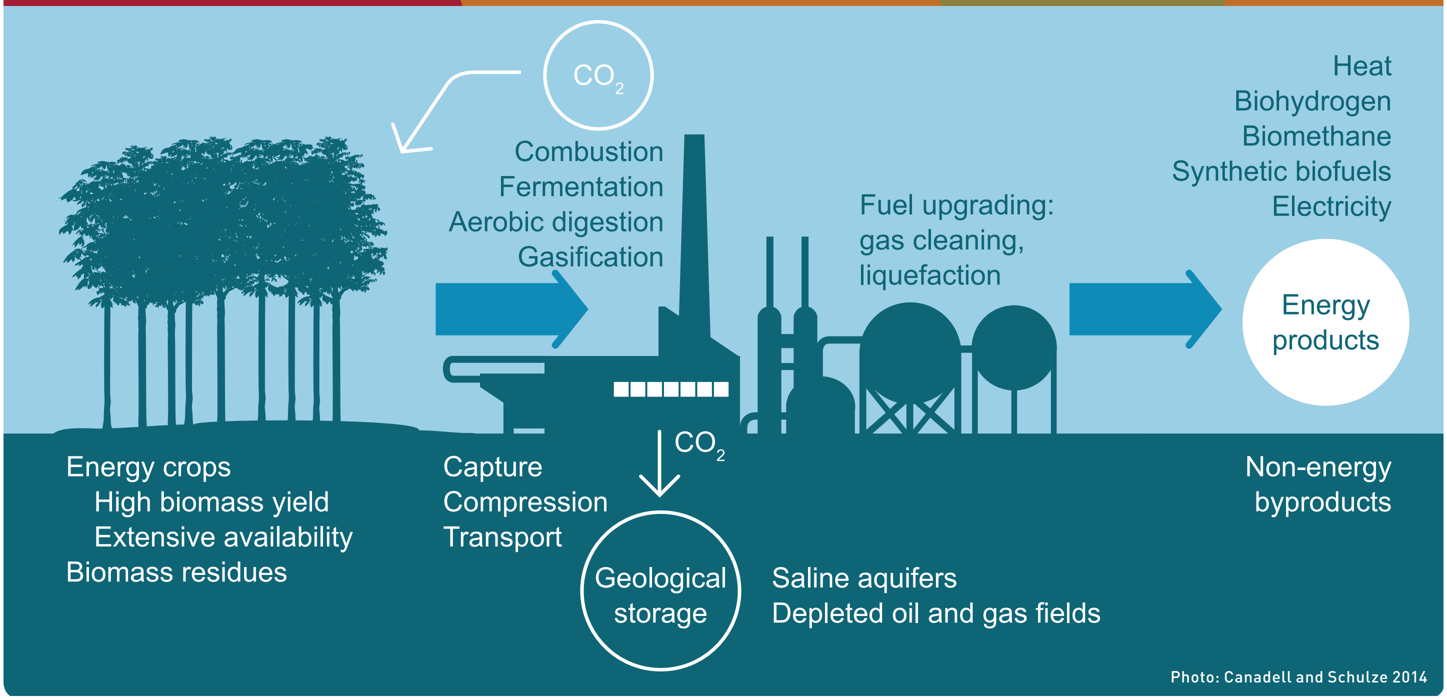
We identify a near-term financial opportunity for existing biorefineries:

- There are over 200 U.S. biorefineries in the United States, producing the equivalent of 6% of energy demand for road transport. These facilities emit 45 million metric tons of CO_2 annually from bioethanol production through fermentation, about 1% of U.S. emissions.
- 60% of this amount (27 million metric tons of CO2 per year) could be captured and compressed for pipeline transport for under \$25 per ton.
- A sequestration credit, similar to existing tax credits, of \$60 per metric ton of CO_2 could lead to 30 million tons of sequestration (equivalent to emissions from about 6 million cars taken off the road) and spur construction of approximately 4,300 miles of pipeline infrastructure.
- A carbon abatement credit, similar to existing tradeable CO_2 credits, of \$90 per metric ton of CO_2 could lead to 38 million tons of abatement.

Iowa farmland.

Photo: Steven Vaughn

An ethanol plant in West Burlington, Iowa.



Bioenergy with carbon capture and sequestration (BECCS) technologies capture and permanently store CO_2 emissions released during the production of heat, fuels, or electricity from biomass.

- Aggregation of CO_2 sources enables cost-effective long-distance pipeline transport to distant storage sites.

Existing and proposed policies suggest a substantial near-term opportunity for deploying BECCS:

The U.S. and other countries have developed energy and climate policies that could incentivize carbon removal from existing biorefineries. These policies exist at the sub-national, national, and international level.

- Newly revised tax policy in the U.S. can produce revenues for existing ethanol biorefineries. The Bipartisan Budget Act of 2018 (H.R. 1892) includes a section 45Q tax credit of up to $50 per metric ton of CO_2 sequestered in secure geologic storage for a 12-year duration. Smaller tax credits are also available for enhanced oil recovery operations.
- Several states and provincial jurisdictions (e.g. California, Oregon, British Columbia) have implemented low-carbon fuel standards, which are market-based policies to reduce the lifecycle carbon intensity of transportation fuels over time. These systems provide an economic incentive for emissions abatement in biofuel production.
- California is in the process of adopting a quantification methodology and permanence protocol for capture and storage of CO_2. Should this occur, biorefiners will be able to provide an additional source of low-carbon fuels for California.
- Canada is currently the largest importer of U.S. ethanol. Should it implement a national clean fuels standard, it could serve as an additional market driver for carbon removal.
- In contrast to other policy instruments, the U.S. Renewable Fuels Standard (RFS) provides limited support for deployment. Nevertheless, the U.S. Environmental Protection Agency has proposed registration, recordkeeping, and reporting requirements to allow carbon removal in the RFS.

Benefits for carbon capture technology, biofuels, and carbon removal:

Carbon removal at biorefineries can have broader benefits for deploying carbon capture and sequestration technologies. Specifically, it can:

- Develop experience in carbon sequestration, project finance, and business models for carbon storage and carbon removal.
- Begin immediately. Implementation does not rely on widespread deployment of costly or unproven solvents, sorbents, or membranes, unlike some other technologies for carbon removal.
- Provide valuable experience for future cellulosic biorefineries equipped with carbon removal. Cellulosic biorefineries with carbon removal can achieve net-negative lifecycle emissions. Furthermore, there is a geographic overlap between existing ethanol biorefineries and potential cellulosic feedstocks like agricultural residues and dedicated energy crops.

Points for Policymakers

- Ethanol production at biorefineries is a low-cost entry point for carbon capture and storage in the United States.
- Carbon capture paired with permanent sequestration can reduce the carbon intensity of existing ethanol production.
- The majority of Midwestern biorefineries are not co-located with suitable sites for geologic sequestration of CO_2, meaning that planning, permitting, and financial incentives for the construction of CO_2 transport networks would be needed to achieve carbon removal.
- Allowing carbon removal in low-carbon fuel standards would encourage carbon capture and sequestration at biorefineries.
- The U.S. Renewable Fuel Standard (RFS) could be altered to better incentivize BECCS deployment.

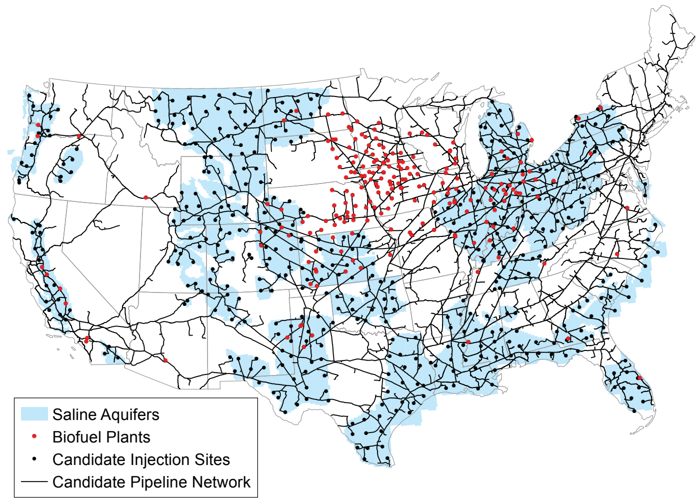


Illustration: Sanchez et al. 2018

Existing and planned ethanol biorefineries, saline aquifers for permanent storage of CO_2, candidate CO_2 pipelines, and candidate injection sites in the U.S.

Conclusion

Carbon capture and storage at existing bioethanol refineries is a largely untapped financial opportunity. The benefits are multiple. It could catalyze the growth of carbon capture, transport, and sequestration technologies and industries. The lifecycle impacts of conventional biofuels would be improved, while supporting development of carbon-negative fuels. And it can help fulfill the mandates of low-carbon fuel policies across the U.S. Furthermore, existing and proposed policies appear poised to make carbon removal cost-effective. Deploying carbon removal at existing biorefineries is an important step forward towards understanding the potential for large-scale CO_2 removal from the atmosphere.

This brief is based on the paper "Near-term deployment of carbon capture and storage from biorefineries in the United States" published in *Proceedings of the National Academies of Sciences* by Daniel Sanchez, Nils Johnson, Sean McCoy, Peter Turner, and Katharine Mach.